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Effects of the floods on dysentery in north central region of Henan Province, China from 2004 to 2009

Wei Ni [a,b], Guoyong Ding [c], Yifei Li [a,b], Hongkai Li [a,b], Qiyong Liu [b,d], Baofa Jiang [a,b,*]

[a] *Department of Epidemiology and Health Statistics, School of Public Health, Shandong University, Jinan City, Shandong Province, 250012, PR China*
[b] *Shandong University Climate Change and Health Center, Jinan City, Shandong Province, 250012, PR China*
[c] *Department of Occupational and Environmental Health, School of Public Health, Taishan Medical College, Taian City, Shandong Province, 271016, PR China*
[d] *State Key Laboratory for Infectious Diseases Prevention and Control, National Institute for Communicable Disease Control and Prevention, China CDC, Beijing City, 102206, PR China*

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Summary *Objectives:* Zhengzhou, Kaifeng and Xinxiang, the cities in the north central region of Henan Province, suffered from many times floods from 2004 to 2009. We focused on dysentery disease consequences of floods and examined the association between floods and the morbidity of dysentery, based on a longitudinal data.
Methods: A generalized additive mixed model was conducted to examine the relationship between the monthly morbidity of dysentery and floods from 2004 to 2009 in the study areas. The relative risks (RRs) of the floods risk on the morbidity of dysentery were estimated in each city and the whole region.
Results: The RRs on dysentery were 11.47 (95% CI: 8.67–15.33), 1.35 (95% CI: 1.23–3.90) and 2.75 (95% CI: 1.36–4.85) in Kaifeng, Xinxiang and Zhengzhou, respectively. The RR on dysentery in the whole region was 1.66 (95% CI: 1.52–1.82).

* Corresponding author. Department of Epidemiology and Health Statistics, School of Public Health, Shandong University, No. 44 Wenhuaxi Road, 250012, Jinan, PR China. Tel.: +86 0531 88382141; fax: +86 0531 88382128.
E-mail addresses: bjiang@sdu.edu.cn, bjiang2013@gmail.com (B. Jiang).

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Conclusions: Our study confirms that flooding has significantly increased the risk of dysentery in the study areas. Additionally, we observed that a sudden and severe flooding can contribute more risk to the morbidity of dysentery than a persistent and moderate flooding. Our findings have significant implications for developing strategies to prevent and reduce health impact of floods.

Introduction

Due to climate change, floods are recognized as the most frequent and devastating type of natural disasters in the world.[1] The number of global flood events doubled from 2001 to 2010. China frequently experiences natural disasters, of which flooding is the most serious.[2] Yellow River Basin, the second large river in China, has unique river valley topography. Climate change brought abundant rainfall and frequent storm floods to the north central region of Henan Province, where the Yellow River meandered. Consequently, the persistent and heavy precipitation led to several floods in Zhengzhou, Kaifeng and Xinxiang cities-in the north center Henan Province between 2004 and 2009.[3–7]

Floods are known to cause heavy physical damages during the initiation phase, but as floodwaters recede there are more threats to personal health and safety. Floods are associated with an increased risk for diarrheal diseases.[8] Some studies have shown this effect that diarrheal diseases can increase in weeks or months after floods both in developing and developed countries. For example, Schwartz et al. found that in all flood-associated diarrheal epidemics (1998–2004) cholera was a predominant cause compared to control period in Dhaka, Bangladesh.[9] In a large study undertaken in Indonesia in 1992–1993, floods were identified as a significant risk factor for diarrheal illnesses caused by *Salmonella enterica* serotype Paratyphi A (paratyphoid fever).[10] A study from Germany revealed that contact with flood-water was significantly associated with onset diarrhea (OR = 5.8, 95% CI: 1.3–25.1).[11] In addition, an increased risk of gastroenteritis following the floods in 2000 has been reported in Lewes, England through a historical cohort study by Reacher et al.[12]

Dysentery, including bacillary dysentery and amebic dysentery as diarrheal diseases, remains a major public health problem in Henan Province. The incidence of dysentery each year ranged from 16.38 to 40.14 per 100,000 in Henan during 2004–2009,[13] which was the second highest among the 39 species of notified infectious diseases. The health effects of floods may include increased mortality and morbidity from dysentery. Although some studies considering dysentery as a flood-related disease found that the rate of dysentery increased after floods,[14–16] there has been no research quantifying the effect of floods on dysentery to our knowledge. The evidence on the association between floods and dysentery is far from clear. Some studies also showed that after fully controlling for the difference with pre-flood rates and seasonality, there was no clear evidence of excesses found in dysentery risk during or after flooding.[17,18] Additionally, the IPCC fourth assessment report has reflected that there is little research on floods and human health in China. Therefore, this study aimed to explore the potential association between dysentery and floods based on a longitudinal analysis from 2004 to 2009 in Zhengzhou, Kaifeng and Xinxiang cities. Results will contribute to have a better understanding of the health impacts of floods and assist in developing national strategies to prevent and reduce the risk of infectious diseases with floods.

Materials and methods

Study areas

Fig. 1 shows the geographic position of the three cities in the north center of Henan Province, which are located in the middle reaches of the Yellow River. The similar geographic location determines these cities the characteristics of the warm temperate continental monsoon climate. Kaifeng is located between latitude 34°11′–35°01′N and longitude 113°52′–115°15′E with an annual average temperature from 13.7 to 15.8 °C and an annual average rainfall from 585.3 to 684.1 mm.[19] Zhengzhou, the capital of Henan Province, is located between latitude 34°16′–34°58′N and longitude 112°42′–114°14′E with an annual average temperature from 13.7 to 14.2 °C and an average rainfall per year up and down in 640.9 mm.[20] In addition, Xinxiang is located between latitude 34°55′–35°50′N and longitude 113°30′–115°30′E with an annual average temperature from 13.9 to 14.6 °C, and an annual average rainfall per year of 580–640 mm.[21] The areas of Zhengzhou, Kaifeng and Xinxiang are 7446.2, 6444 and 8629 square kilometers, respectively. In 2009, the population of Zhengzhou was approximately 682 million, followed by 475 million in Kaifeng and 562 million in Xinxiang.

Data collection and management

Disease surveillance data

Monthly disease surveillance data on dysentery from January 2004 to December 2009 were obtained from the National Notifiable Disease Surveillance System (NDSS). The definition of dysentery from the NSDD is a group of the

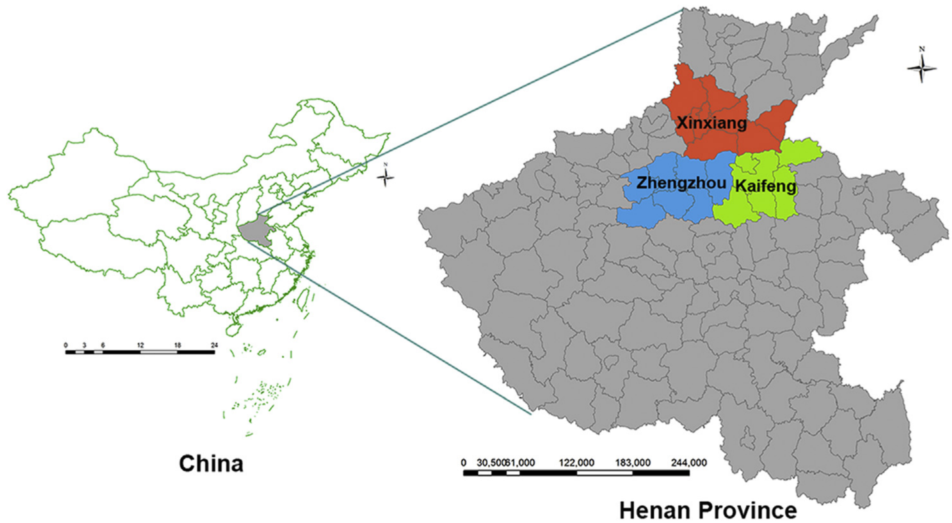

Figure 1 Location of Kaifeng, Zhengzhou and Xinxiang in Henan Province, China.

human diseases that are caused by *Shigellae* and protozoan parasite *Entamoeba histolytica*, which have fever, abdominal pain, tenesmus and bloody or mucus stool as the typical clinical presentation. In our study, all dysentery cases were defined based on the diagnostic criteria and principles of management for dysentery (GB 16002-1995) issued by Ministry of Health of the People's Republic of China.[22] Only the cases confirmed clinically and by laboratory tests, including microscopic examination and biochemical identification, were included in our study. Information of cases included age, gender, occupation, address, name of disease, cases classification, date of onset, and date of death. The gastrointestinal diseases caused by intoxication and chemical factors were a type of food poisoning with non-communicable, which were not under the surveillance and notification in the NDSS of China. These gastrointestinal diseases were not included in our study.

In China, dysentery is a statutory notifiable category B infectious disease. According to the National Communicable Disease Control Act, physicians in hospitals must report every case of dysentery to the local health authority. Then, the local health authority must report these cases to the next level of the organization within 24 h.[23] Therefore, it is believed that the degree of compliance in disease notification over the study period was consistent.

Data of floods

The Yearbooks of Meteorological Disasters in China recorded the occurrence, deaths, damage area and economic loss of floods in detail from 2004 to 2009.[24] According to the Yearbooks of Meteorological Disasters in China, there were seven times of floods recorded in Kaifeng and Xinxiang from 2004 to 2009, which was less than that of Zhengzhou with nine times of floods.

Flooding per se would be a variable depending on the quantitation over a shorter period time than a month. But in our study, we analyzed monthly data to assess the effects of floods on the dysentery disease on the basis of a time series data from 2004 to 2009, which included flooded months, non-flooded months, pre-flooded and post-flooded months, and the same period over other years, so monthly data would estimate the effects of floods well.

Demographic and meteorological data

Demographic data were obtained from the Center for Public Health Science Data in China (http://www.phsciencedata.cn/). Monthly meteorological data were obtained from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). The meteorological variables included monthly cumulative precipitation (MCP), monthly average temperature (MAT), monthly average relative humidity (MARH) and monthly cumulative sunshine duration (MCSD).

Statistical analysis

Firstly, a descriptive analysis was performed to describe the distribution of dysentery cases and meteorological factors between the flooded and nonflooded months through the Kruskal–Wallis H test. Spearman correlation was adopted to examine the association between floods, climatic variables and the morbidity of dysentery with various lagged values in each city. The lagged value with the maximum correlation coefficient for each climate variable was selected for inclusion in the subsequent regression models. According to the reproducing of pathogen and the incubation period of dysentery disease, a time lag of 0–2 months was considered in this study.[25]

The widely used generalized additive models (GAM) method is a flexible and effective technique for conducting nonlinear regression analysis in time-series studies with a Poisson regression.[26] GAM allows this Poisson regression to be fit as a sum of nonparametric smooth functions of predictor variables. The purpose of GAM is to maximize the predictive quality of a dependent variable, "Y" from various distributions by estimating archetypical function of the predictor variables that connected to the dependent variable. In time-series studies of air pollution and mortality, GAM has been the most widely applied method, because it allows for nonparametric adjustment for nonlinear confounding effects of seasonality, trends, and weather variables.[27–29]

In our study, the Poisson regression, using a Generalized Additive Mixed Model (GAMM), was developed allowing the parametric and nonparametric functions to be analyzed together in the model. In several studies, mean temperature, cumulative precipitation, average relative humidity and sunshine duration were found to associate with diarrheal diseases.[30–34] Consequently, the model was performed to evaluate the association between the morbidity of dysentery and floods with adjustment for the multiple-lag effects of monthly mean temperature, monthly cumulative precipitation, monthly average relative humidity and sunshine duration. Firstly, the effects of floods on dysentery in each city were analyzed by the GAMM. The regression model was described as follows:

$$\begin{aligned}\ln(Y_t) = {} & \beta_0 + \beta_1(\mathit{floods}) + \beta_2(\mathit{flood\ duration}) + s_1(\mathit{precipitation}) \\ & + s_2(\mathit{temperature}) + s_3(\mathit{relative\ humidity}) + s_4(\mathit{sunshine\ duration}) \\ & + s_5(t) + s_6(\sin 2\pi t/12)\end{aligned}$$

All the three cities are located in the north central Henan Province, and adjacent to each other. And then, the overall effects of floods on dysentery were evaluated in all the three cities. The overall function was as follows:

$$\begin{aligned}\ln(Y_t) = {} & \beta_0 + \beta_1(\mathit{floods}) + \beta_2(\mathit{flood\ duration}) + \beta_3(\mathit{city}) + s_1(\mathit{precipitation}) \\ & + s_2(\mathit{temperature}) + s_3(\mathit{relative\ humidity}) + s_4(\mathit{sunshine\ duration}) \\ & + s_5(t) + s_6(\sin 2\pi t/12)\end{aligned}$$

Where Y_t denoted the monthly morbidity of dysentery at time t, which represented the specific month; the parameters were individually represented by β_0 from β_2 in the first regression model and β_0 from β_3 in the second regression model, respectively. The values and confidence interval of RRs of floods and flood duration on dysentery were the natural logarithms of corresponding parameters. *Floods* was a categorical variable including non-flood and floods endowed by 0 and 1, respectively. *Flood duration* represented the days with flooding in a month. *City*, a variable categorized as Kaifeng, Xinxiang and Zhengzhou endowed by 1, 2 and 3, respectively, was designed to control for the effects of other unobserved factors. $s_1(\mathit{precipitation})$, $s_2(\mathit{temperature})$, $s_3(\mathit{relative\ humidity})$ *and* $s_4(\mathit{sunshine\ duration})$ were smooth functions of monthly cumulative precipitation, monthly mean temperature, monthly average relative humidity and monthly cumulative sunshine duration, respectively, which were designed to control for the effect of weather. The smooth spline of specific month was projected as $s_5(t)$ in order to avoid the influence of long-term trend. Considering the effects of seasonality on dysentery, the proposed model included a triangular function, $\sin(2\pi t/12)$, to reveal the seasonal component in series. The statistical analysis was performed using SPSS 16.0 (SPSS Inc., USA) and software R 2.3.1 (MathSoft Inc., USA).

Results

Descriptive analysis for the disease and meteorological data

A total of 24,536 cases of dysentery were notified in the study areas over non-flooded and flooded months from 2004 to 2009. Among all the cases, the dysentery caused by *Shigellae* accounted for 99.00%, far more than the dysentery caused by the protozoan parasite *E. histolytica* with 1.00%. Tables 1–3 show that the incidence of dysentery, MCP, MAT, MARH and MCSD were significantly different between non-flooded and flooded months ($p < 0.05$) in both cities, which indicated that climatic conditions differed between the months with or without floods. During the flooded months, the morbidity of dysentery was higher than the non-flooded months, followed by more precipitation, higher temperature, higher relative humidity and more sunshine duration. Fig. 2 shows that the morbidity of dysentery declined from 2004 to 2009, and more cases occurred in spring and summer in these cities.

Spearman's correlation analysis

Table 4 shows the results of Spearman's correlation test conducted to determine the lagged effects between the morbidity of dysentery and explanatory variables during the study period in each city. The results indicated that the floods were positively correlated to the monthly morbidity of dysentery with no month lagged among the three cities. The lagged values of climatic variables in these cities were the same except for the monthly average temperature in Kaifeng according to the coefficients in Table 4.

Regression analysis

The parameters of the models and RRs of floods on the risk of dysentery are presented in Table 5. Results showed that floods were significantly associated with the morbidity of dysentery in each of the three cities (Coefficients: 2.44 in Kaifeng; 0.30 in Xinxiang; and 1.01 in Zhengzhou).

Table 1 Description of dysentery cases and climate variables from 2004 to 2009 in Kaifeng City.

Variable	Period	Mean ± SD	Min	P_{25}	Median	P_{75}	Max
The monthly morbidity of dysentery ($1*10^{-8}$)	Non-flooded months	119 ± 193	2	41	61	111	1386
	Flooded months*	293 ± 166	104	175	282	340	619
MFD (days)	Flooded months	3 ± 1	1	2	3	5	5
MCP (mm)	Non-flooded months	44.4 ± 58.5	0	7.1	14.8	61.3	262.8
	Flooded months*	155.6 ± 95.2	61.6	95.5	121.4	241.1	328.4
MAT (°C)	Non-flooded months	14.5 ± 9.1	−0.8	5.7	16.4	21.7	27.9
	Flooded months*	26.4 ± 1.0	24.8	25.4	26.8	27.2	27.6
MARH (%)	Non-flooded months	59.5 ± 8.9	40.0	54.0	60.0	65.0	76.0
	Flooded months*	75.3 ± 4.1	68.0	71.0	79.0	78.0	79.0
MCSD (h)	Non-flooded months	150.0 ± 50.4	45.4	117.9	141.3	195.0	258.8
	Flooded months*	123.9 ± 30.7	79.3	109.2	118.0	136.7	180.2

SD: standard deviation; Min, minimum; P_{25}, the 25th percentile; P_{75}, the 75th percentile; Max, maximum.
MFD, the monthly flood duration; MCP, monthly cumulative precipitation; MAT, monthly average temperature; MRH, monthly relative humidity; MCSD, monthly cumulative sunshine duration.
*$p < 0.05$ vs. non-flooded month.

However, flood duration was negatively correlated with the morbidity of dysentery (Coefficients: −0.63 in Kaifeng; −0.50 in Xinxiang and −0.36 in Zhengzhou). During the flooded months, floods were significantly associated with an increased risk of dysentery with adjustment for meteorological factors in Kaifeng (RR = 11.47, 95% CI: 8.67—15.33). The RRs of dysentery for floods in Xinxiang and Zhengzhou were 1.35 (95% CI: 1.23—3.90) and 2.75 (1.36, 4.85), respectively.

In addition, the overall effects of floods on dysentery in the entire region were estimated through the overall function. As shown in Table 6, an increased risk of dysentery in this region was found, which indicated that floods could increase the morbidity of dysentery in flooded months (RR = 1.66, 95% CI: 1.52—1.82). This overall model also indicated the extent of dysentery epidemics in the cities. Compared with Kaifeng city, the intensity of dysentery epidemic in Zhengzhou was the greatest with the highest morbidity in terms of the coefficients of the model (Coefficient: 1.13, 95% CI: 1.11—1.16), followed by Xinxiang with lower intensity and morbidity (Coefficient: 0.19, 95% CI: 0.15—0.22).

Discussion

Our study is the first time to demonstrate the quantitative risk of the relationship between the morbidity of dysentery and floods on the basis of a longitudinal data from 2004 to 2009. The results indicated that floods play an important role in the dysentery epidemics during the flood-month. Although the study is based on north central Henan Province, the real impact of dysentery due to floods will be much larger than the estimates from this study, given the larger population at risk in China. Determining the effect of floods on dysentery would be beneficial for providing a basis for the policy making for dysentery control technologies.

This study has indicated that the morbidity of dysentery during the flooded months could be higher than the non-flooded month. During the flooded months, heavy rainfall may cause floods and change in the living environment. Due mostly to floods after extreme precipitation, water-borne diseases outbreaks and epidemics have been associated with water sources for drinking and recreation.[35—38]

Table 2 Description of dysentery cases and climate variables from 2004 to 2009 in Zhengzhou City.

Variable	Period	Mean ± SD	Min	P_{25}	Median	P_{75}	Max
The monthly morbidity of dysentery ($1*10^{-8}$)	Non-flooded months	390 ± 349	56	160	245	478	1634
	Flooded months*	569 ± 315	252	327	458	754	1240
MFD (days)	Flooded months	3 ± 1	2	2	3	3.5	4
MCP (mm)	Non-flooded months	37.9 ± 40.5	0	6.9	17.8	59.1	162.1
	Flooded months*	204.6 ± 70.4	118.0	127.3	214.4	267.4	309.7
MAT (°C)	Non-flooded months	14.3 ± 8.9	−0.7	6.8	15.9	21.7	28.8
	Flooded months*	26.5 ± 1.0	24.8	25.7	26.6	27.1	28.2
MARH (%)	Non-flooded months	58.4 ± 9.6	40.0	51.5	58.0	64.0	77.0
	Flooded months*	74.0 ± 8.2	53.0	73.5	77.0	78.0	80.0
MCSD (h)	Non-flooded months	153.0 ± 47.3	50.5	125.4	150.1	188.3	247.0
	Flooded months*	128.4 ± 37.4	78.7	97.2	123.0	151.4	201.5

SD: standard deviation; Min, minimum; P_{25}, the 25th percentile; P_{75}, the 75th percentile; Max, maximum.
MFD, the monthly flood duration; MCP, monthly cumulative precipitation; MAT, monthly average temperature; MRH, monthly relative humidity; MCSD, monthly cumulative sunshine duration.
*$p < 0.05$ vs. non-flooded month.

Table 3 Description of dysentery cases and climate variables from 2004 to 2009 in Xinxiang City.

Variable	Period	Mean ± SD	Min	P_{25}	Median	P_{75}	Max
The monthly morbidity of dysentery ($1*10^{-8}$)	Non-flooded months	148 ± 146	33	66	103	158	874
	Flooded months*	409 ± 373	131	157	290	511	1200
MFD (days)	Flooded months	3 ± 1	2	2	3	3	3
MCP (mm)	Non-flooded months	47.3 ± 65.4	0	6.9	14.7	63.6	98.4
	Flooded months*	119.2 ± 81.4	118.5	165.1	196.4	211.2	242.5
MAT (°C)	Non-flooded months	14.3 ± 9.1	−1.2	7.2	16.3	21.7	27.9
	Flooded months*	26.6 ± 1.3	24.9	25.3	26.6	27.7	28.3
MARH (%)	Non-flooded months	61.9 ± 9.1	44.0	56.0	61.0	69.0	79.0
	Flooded months*	76.1 ± 4.0	69.0	73.0	78.0	79.0	80.0
MCSD (h)	Non-flooded months	158.8 ± 47.1	55.4	128.5	159.6	187.0	260.4
	Flooded months*	232.6 ± 28.3	184.9	213.6	251.4.1	255.2	256.4

SD: standard deviation; Min, minimum; P_{25}, the 25th percentile; P_{75}, the 75th percentile; Max, maximum.
MFD, the monthly flood duration; MCP, monthly cumulative precipitation; MAT, monthly average temperature; MRH, monthly relative humidity; MCSD, monthly cumulative sunshine duration.
$*p < 0.05$ vs. non-flooded month.

Bacillary and amebic dysentery, as the water-borne disease with cholera, hepatitis A, typhoid fever, and other gastrointestinal diseases, were caused by ingestion of water contaminated by human or animal faeces or urine containing *Shigellae* or the protozoan parasite *E. histolytica*.[39] During the initial stage of the flood, intense precipitation can mobilize pathogens in the environment and transport them into the aquatic environment, increasing the microbiological agents on surface water.[40,41] Floods adversely affected water sources and supply systems, as well as sewerage and waste-disposal systems. The contamination can be washed into water source, causing the local water

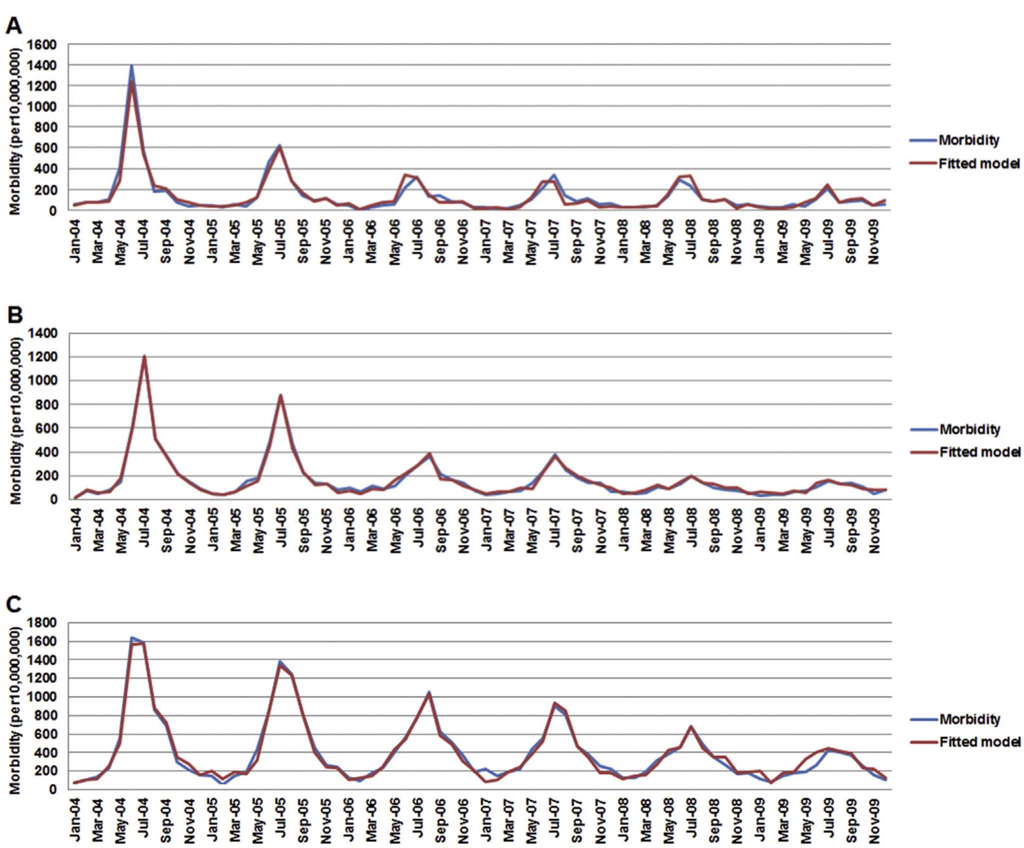

Figure 2 Dynamics of dysentery in the three cities with the analysis of GAMM from 2004 to 2009 (Morbidity per 10,000,000 population). (A) Dysentery of dysentery in Kaifeng City; (B) Dynamics of dysentery in Xinxiang City; (C) Dynamics of dysentery in Zhengzhou City.

Table 4 Correlations between the morbidity of dysentery and explanatory variables among monthly data in the study cities from 2004 to 2009.

City	Lag month	Floods	MFD	MCP	MAT	MARH	MCSD
Kaifeng	0	0.405**	0.402**	0.605**	0.802**	0.432**	0.121
	1	0.240*	0.238*	0.500**	0.787**	0.199	0.410**
	2	0.143	0.136	0.169	0.595**	0.019	0.539**
Zhengzhou	0	0.496**	0.488**	0.688**	0.848**	0.549**	0.087
	1	0.444**	0.438**	0.665**	0.877**	0.322**	0.334**
	2	0.273*	0.265*	0.520**	0.653**	0.019	0.529**
Xinxiang	0	0.362**	0.359**	0.652**	0.771**	0.570**	0.151
	1	0.307**	0.305**	0.630**	0.798**	0.301*	0.383**
	2	0.205	0.205	0.522**	0.626**	0.045	0.526**

MFD, the monthly flood duration; MCP, monthly cumulative precipitation; MAT, monthly average temperature; MRH, monthly relative humidity; MCSD, monthly cumulative sunshine duration.
$*p < 0.05$; $**p < 0.01$.

quality seriously deteriorated and increasing the transmission of enteric pathogens during the floods.[42] Our findings support that the morbidity of dysentery is higher in the summer with floods through the comparison between non-flooded and flooded months.

Our study has identified that the risks of floods on dysentery vary among the three cities, which suggests that floods may affect dysentery via diverse means not only by contaminated water source or foods. Besides the deterioration of the infrastructure, floods also can cause population displacement and changes in population density.[30,43] After controlling for the impacts of weather and seasonality, floods has contributed to an increased risk of dysentery with different RRs among the three cities. The reason for the difference in disease risks among the three cities is not clear. The occurrence or spread of a disease after floods was also affected by other factors such as public health services, population density and demographics, and socio-economic conditions. The reason for the various relative risks between the cities was probably due to the severity of flood and population density. In addition, public health services and socio-economic status were not same in the study areas. Zhengzhou, as the capital of Henan Province, has a higher level of economy, better infrastructure, and better health services and health care than Kaifeng and Xinxiang. Therefore, these advantages lead to a minimal risk of dysentery transmission and epidemics following floods. More population and larger density means more possibilities of transmission and infection. Although Xinxiang has lower political and economic status compared with Zhengzhou, its less external population and density lead to fewer opportunities of transmission and infection for individual. These differences may be explain the different relative risks between the two cities. A study found that as the rapid process of urbanization in Kaifeng, the land structure was changed with increased impervious surface and reducing land area as a result of more concrete structures built on the ground.[44] Moreover, the old drainage system was unscientific and in bad repair, leading to the poor capacity of sewer drainage. During the period of heavy precipitation, flooding is more likely to occur in Kaifeng and floodwater could easily be infected with pathogens through cross-contamination due to infiltration and inflow between sewage and water pipes. In addition, the economic strength of Kaifeng is the worst compared with Zhengzhou and Xinxiang,[45] which means that the financial input is little to the public health and health care. Thus, the relative risk on dysentery after flood was the highest among the three cities.

This study has also indicated that the risk of dysentery after floods in the whole area may not be severe relatively. With the reference of Kaifeng city, Zhengzhou and Xinxiang

Table 5 Parameters coefficients from the Generalized Additive Mixed Model for the dysentery disease.*

City	Variables	Coefficients (95% CI)	*P*-value	RR (95% CI)
Kaifeng	Intercept	5.96 (5.77, 6.15)	<0.01	—
	Floods	2.44 (2.16, 2.73)	<0.01	11.47 (8.67,15.33)
	Flood duration	−0.63 (−0.74, −0.53)	<0.01	0.53 (0.48, 0.59)
Xinxiang	Intercept	5.13 (4.38, 5.88)	<0.01	—
	Floods	0.30 (0.21, 1.36)	<0.01	1.35 (1.23, 3.90)
	Flood duration	−0.50 (−0.81, −0.07)	<0.01	0.61 (0.44, 0.93)
Zhengzhou	Intercept	5.75 (5.73, 5.78)	<0.01	—
	Floods	1.01 (0.31, 1.58)	<0.01	2.75 (1.36, 4.85)
	Flood duration	−0.36 (−0.53, −0.20)	<0.01	0.70 (0.59, 0.82)

*Adjusted R square of the model in Kaifeng was 0.88; 0.97 in Xinxiang; 0.94 in Zhengzhou.

Table 6 Parameters coefficients from the overall model in the entire region for the dysentery disease.*

Variables	Coefficients (95% CI)	*P*-value	RR (95% CI)
Intercept	4.61 (4.59, 4.64)	<0.01	—
Floods	0.51 (0.42, 0.60)	<0.01	1.66 (1.52, 1.82)
Flood duration	−0.14 (−0.17, −0.11)	<0.01	0.87 (0.84, 0.90)
Kaifeng	0^b	—	—
Xinxiang	0.19 (0.15, 0.22)	<0.01	—
Zhengzhou	1.13 (1.11, 1.16)	<0.01	—

*Adjusted R square of the model was 0.75. 0^b presented the reference level.

had a higher intensity of dysentery epidemics after floods. It may be because that the density and mobility of population influence greatly on the transmission of dysentery between people, which is the largest in Zhengzhou as the capital of Henan Province, followed by Xinxiang due to the second level of population density and mobility among the study cities. Moreover, the reason for this difference may be that the local environment of Zhengzhou and Xinxiang were more suitable for the survival and reproduce of the dysentery pathogens compared with Kaifeng.

The results of the multivariate models demonstrate the quantified impact of flood duration on dysentery, indicating a negatively correlation between flood duration and the morbidity of dysentery. The risk of dysentery could be higher after a sudden and severe flooding than that after a prolonged and moderate flooding. During the sudden and severe flooding, heavy precipitation was strongly destructive for human and health infrastructure, which may cause serious floodwater contamination. In this case, more people would be contact with floodwater, resulting in a greater likelihood of being infected with dysentery. However, during a prolonged and moderate flooding, the transmission and infection of dysentery pathogens may be decreased due to lower destruction and contamination.

Research examining the effect of flood on infectious diseases on a basis of retrospective data collection had methodological shortcomings with a lack of longitudinal analysis.[46] In our study, we used a time-series data from 2004 to 2009 to analyze the effects of many times floods on the onset of dysentery. It provides clear evidence of the relative risk on dysentery after floods. In addition, we have analyzed the difference of risks between the regions on a basis of three cities located in the north central Henan Province. However, some limitations of this study should be acknowledged. One of the limitations is that the effects of many factors, such as population, social and economic status, health services and environmental hygiene, were not quantified precisely. Moreover, due to a lack of detailed laboratory information, we did not analyze the pathogens and the difference in pathogens, and the impact of pathogens on the different relative risks among the cities. A study analyzing the epidemic and aetiological character of bacillary dysentery in Henan Province from 2005 to 2009 found that *Shigella flexneri* was the dominant strains in the province where the study cities located, and the dominant sertypings were *S. flexneri 2a*, *S. flexneri 4c* and *S. flexneri 1a*.[47] These strains may be associated with floods in the three cities during the study period. In addition, under reporting was inevitable in passive disease surveillance systems such as where we obtained our data for the current study and the notified cases were those with severe symptoms that chose to visit doctors in a hospital.[48] Some people with mild clinical symptoms and self-treated cases might not seek medical help. This could lead to an underestimation of the risk of dysentery due to floods.

Conclusion

This study has, for the first time, quantified the effects of floods on dysentery in a region including several cities. Flooding can significantly increase the risk of dysentery in the study areas. Moreover, results reveal that the risk of floods could be different between different areas. Additionally, the risk for dysentery may be higher during and after a sudden and severe flooding than a prolonged and moderate flooding. Our findings have significant implications for developing strategies to prevent and reduce health impact of floods.

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